NASA CR-132284

THE SHOCK TUBE AS A TOOL FOR DYNAMIC TESTING OF FABRICS

Richard Madden
Anthony R. Clemente
James D. Blackwell

Prepared Under Contract No. NAS1-10024 by

Bolt Beranek and Newman Inc.
50 Moulton Street
Cambridge, Massachusetts 02138

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Langley Research Center
Hampton, Virginia

ABSTRACT

Specimens of fabric and Mylar were loaded to failure both statically and dynamically. Static tests were accomplished by pressurizing the specimens and dynamic tests were conducted by firing a shock tube. The results of the study indicate that seam efficiency is degraded by dynamic loads and that a need exists to investigate a seaming procedure which gives an optimum dynamic efficiency. The study also illustrates the lack of correspondence between static and dynamic breaking strengths thereby indicating that fabrics which have dynamic applications should be evaluated using dynamic testing procedures such as the shock tube loading used in the present program.

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

THE SHOCK TUBE AS A TOOL FOR DYNAMIC TESTING OF FABRICS

Richard Madden
Anthony R. Clemente
James D. Blackwell

Bolt Beranek and Newman Inc.
Cambridge, Massachusetts

INTRODUCTION

Woven fabric structures, owing to their relatively high strength to weight ratio and stowability, have been used in a number of aerospace applications. In spite of the many applications for woven structures, testing and qualification techniques have been developed only for very simple cases. The literature describes many static uniaxial tensile tests on single yarns but few on woven fabrics. Although uniaxial testing yields a great deal of information about a fabric, it does not adequately describe fabrics in a state of biaxial stress. Static biaxial testing techniques and apparatus are also very limited. The information that does exist on fabrics in a biaxial state of stress has been obtained through two testing techniques: in one a cross of fabric is pulled in two directions [1]; in the other a cylinder of fabric is inflated and then pulled and twisted [2,3,4]. The results show that fabrics may be nonlinear, anisotropic, load path dependent, and, consequently, cumbersome to deal with analytically. It therefore appears advisable to develop testing procedures that would subject fabrics to loads similar to those expected in service.

For materials having dynamic applications it would certainly seem beneficial to use dynamic testing procedures. As pointed out in Ref. 5, dynamic testing of individual yarns and of webbings has received a great deal of attention and has demonstrated the influence of strain rate on behavior. Dynamic testing of fabrics is much less common but some literature does exist, e.g., Ref. 5. Unfortunately, these tests have been restricted to uniaxial loading, even though biaxial effects are no doubt significant.

The aim of the present program was therefore to develop a simple, dynamic biaxial testing technique that would allow quick evaluation of fabric specimens. The remainder of the report discusses the testing apparatus, the specimens, the results of the testing program, and recommendations for future testing.

TEST APPARATUS

Testing was conducted on the 10-in.-diameter 300-psig shock tube constructed for NASA Langley and discussed in detail in Ref. 6. Fabric specimens were constrained during test by fabric holding brackets also discussed in Ref. 6. The following paragraphs briefly describe the shock tube, the brackets, and the method used to photograph typical failures.

Shock Tube

The shock tube employed in the present program is shown in Fig. 1. The nominal diameter of the tube is 10 in.; the inside diameter and, consequently, the specimen diameter are 10.5 in. In the configuration used, the driver section was 10 ft long and the driven section 20 ft long. The cylindrical specimens were mounted between sections of the shock tube at a point 10 ft from the driver section and the flat circular specimens were mounted at a point 20 ft from the driver section. A schematic drawing of the pressure time history at a point in either test section is given in Fig. 2. Scales are not presented since this drawing merely illustrates phenomena.

This history is composed of a constant pressure region followed by an approximately exponential decay of pressure. A rough estimate of the duration of the constant pressure is 10 ms for the cylindrical specimen and 8 ms for the flat circular specimen. Inspection of films taken of typical fabric failures indicates that these durations exceed the time required for the specimens to fail.

Fabric Holding Brackets

Two types of fabric holding brackets were developed. The first holds flat circular specimens which are mounted on the end of the shock tube. A specimen mounted in this manner experiences a constant pressure over its surface at the arrival of the shock. The second type of bracket holds cylindrical specimens which are mounted along the shock tube.

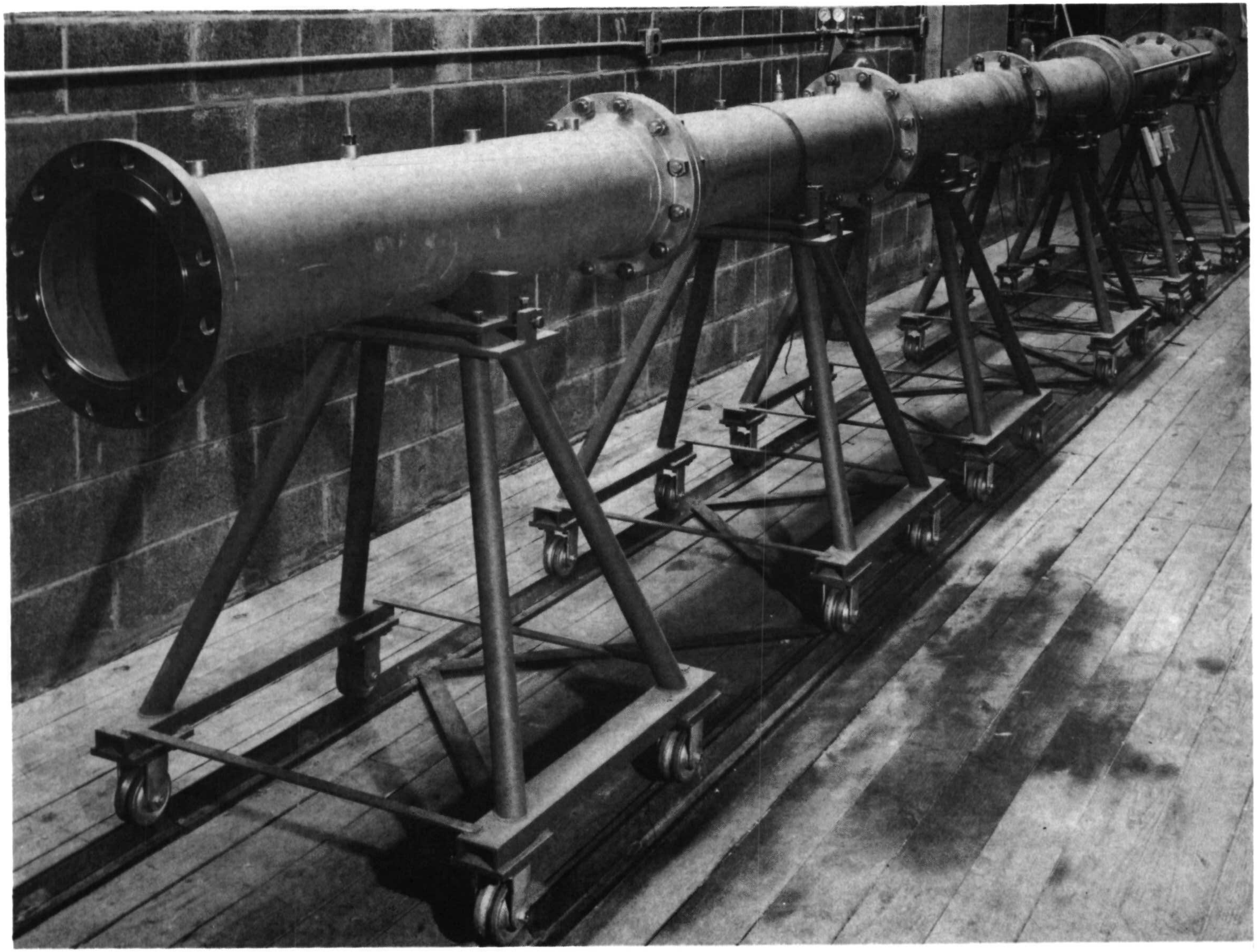

FIG. 1. TEN INCH DIAMETER SHOCK TUBE

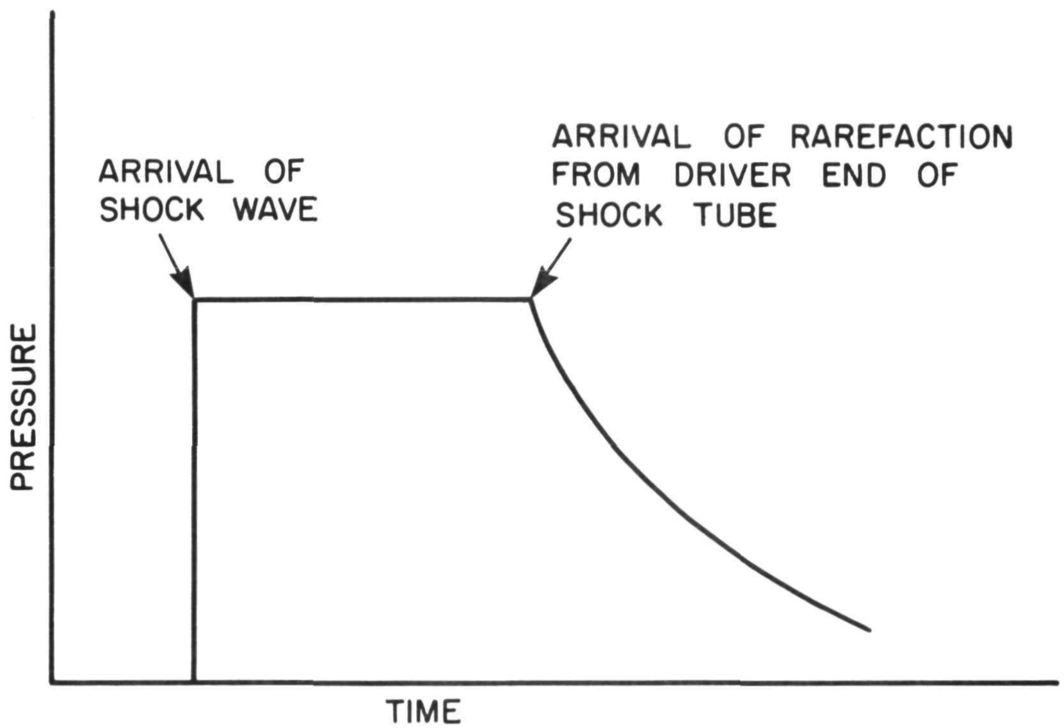

FIG. 2. SCHEMATIC OF PRESSURE TIME HISTORY AT AN ARBITRARY LOCATION ALONG THE SHOCK TUBE

In this case the shock wave travels along the specimen. The latter loading is somewhat similar to that which occurs during deployment of a parachute.

Photographs of the fabric holding bracket for flat circular specimens are shown in Figs. 3 and 4. As shown in Fig. 3, the main components of this bracket are a smooth toroidal shell on which the fabric is mounted and a tension adjusting ring which is split into four quadrants. Each quadrant is fitted with bearings which slide on two ground rods. Tension is adjusted by turning a nut on the threaded rod at the center of the quadrant. Figure 4 shows the fabric specimen in place prior to a test run.

Figures 5 and 6 are photographs of the bracket for cylindrical specimens. As shown in Fig. 5, it is much simpler than the bracket required for flat specimens. It is composed of two end brackets which mount to the flanges on the shock tube and three spacer bars which may be used to adjust the initial tension in the specimen. Figure 6 shows a fabric specimen in place prior to a test run.

Instrumentation

Instrumentation for the tests was rather simple. The only physical parameter that had to be obtained prior to each run was driver pressure, which was measured using a standard 0 to 50 psig gauge with stated accuracy of 0.5 psig. Failures of typical specimens were monitored photographically.

The photographic system consisted of a FASTAX camera operating at approximately 9000 pictures per second (pps). Timing marks spaced 0.001 sec apart were put on the film to ascertain film speed during any portion of the run. We used a 450-ft roll of KODAK 2498 RAR 16 mm film during each run. The camera reached 9000 pps at approximately 1.6 sec (200 ft into the roll) and reached the end of the film at approximately 2.3 sec. Camera sequencing therefore required that a complete event must occur during a specified time window of approximately 0.7 sec. When the shock tube operates in a double diaphragm configuration, it requires from 1 to 3 sec to fire after the fire button is pressed. The

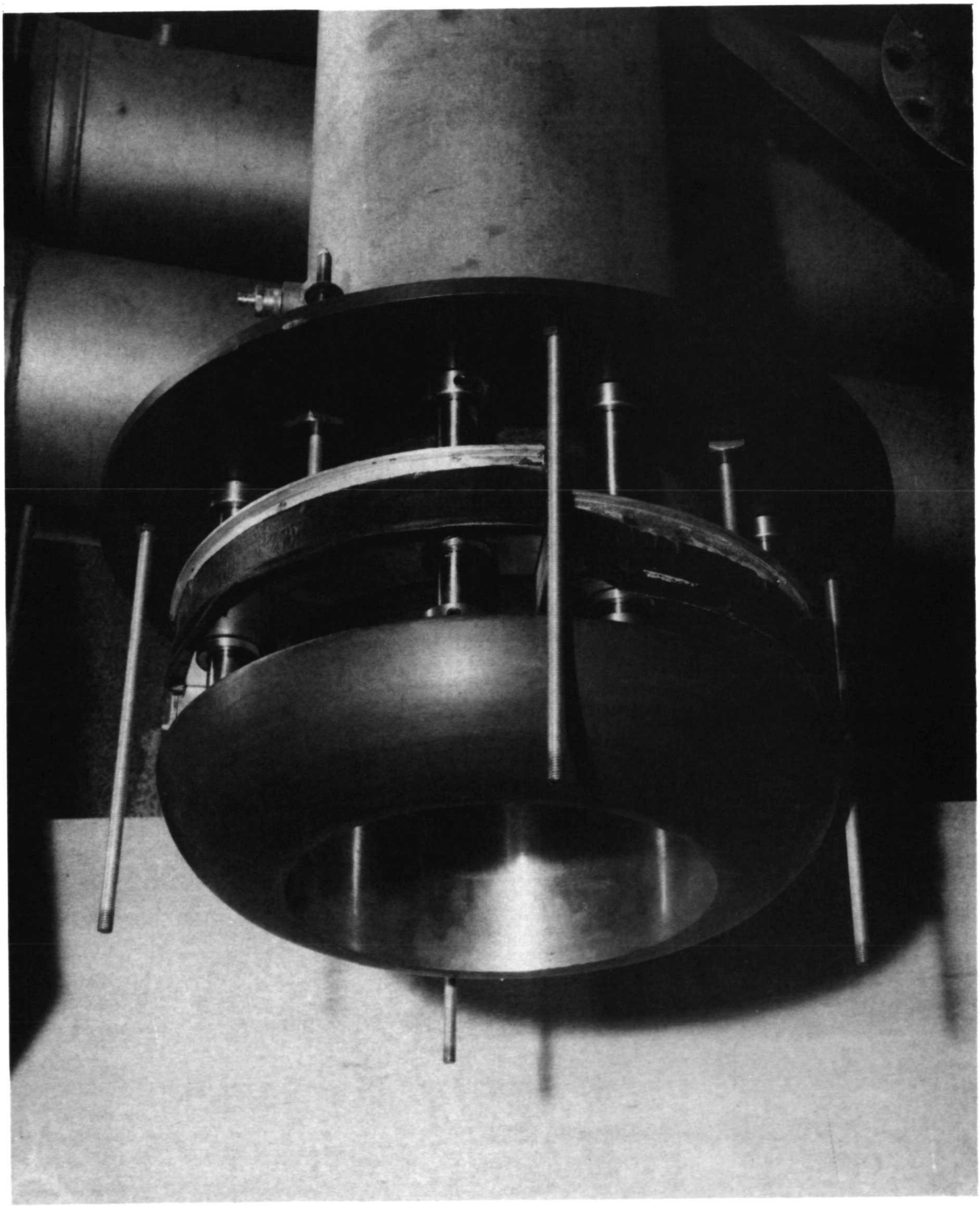

FIG. 3. BRACKET FOR FLAT CIRCULAR FABRIC SPECIMENS

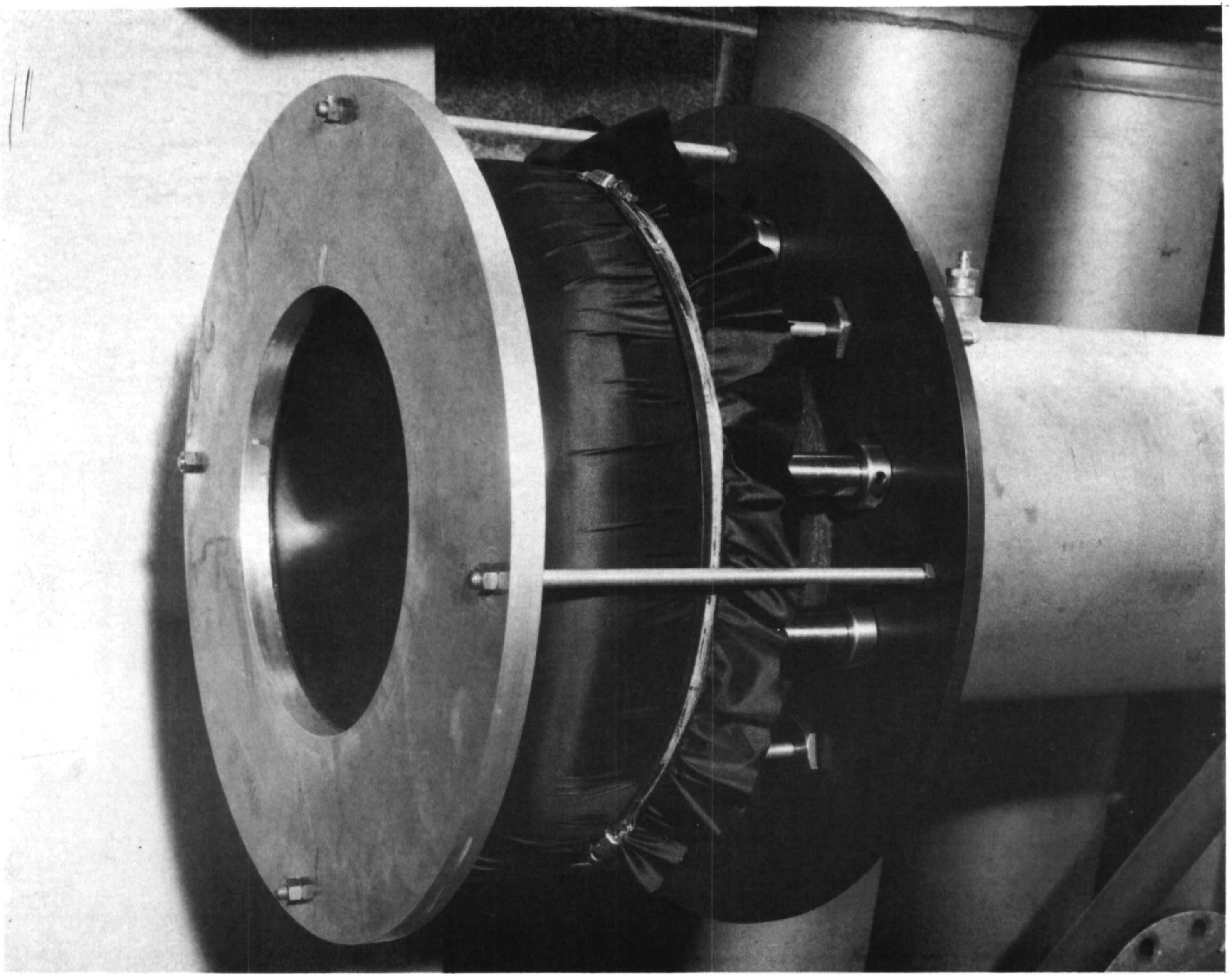

FIG. 4. BRACKET FOR FLAT CIRCULAR FABRIC SPECIMENS (WITH FABRIC INSTALLED)

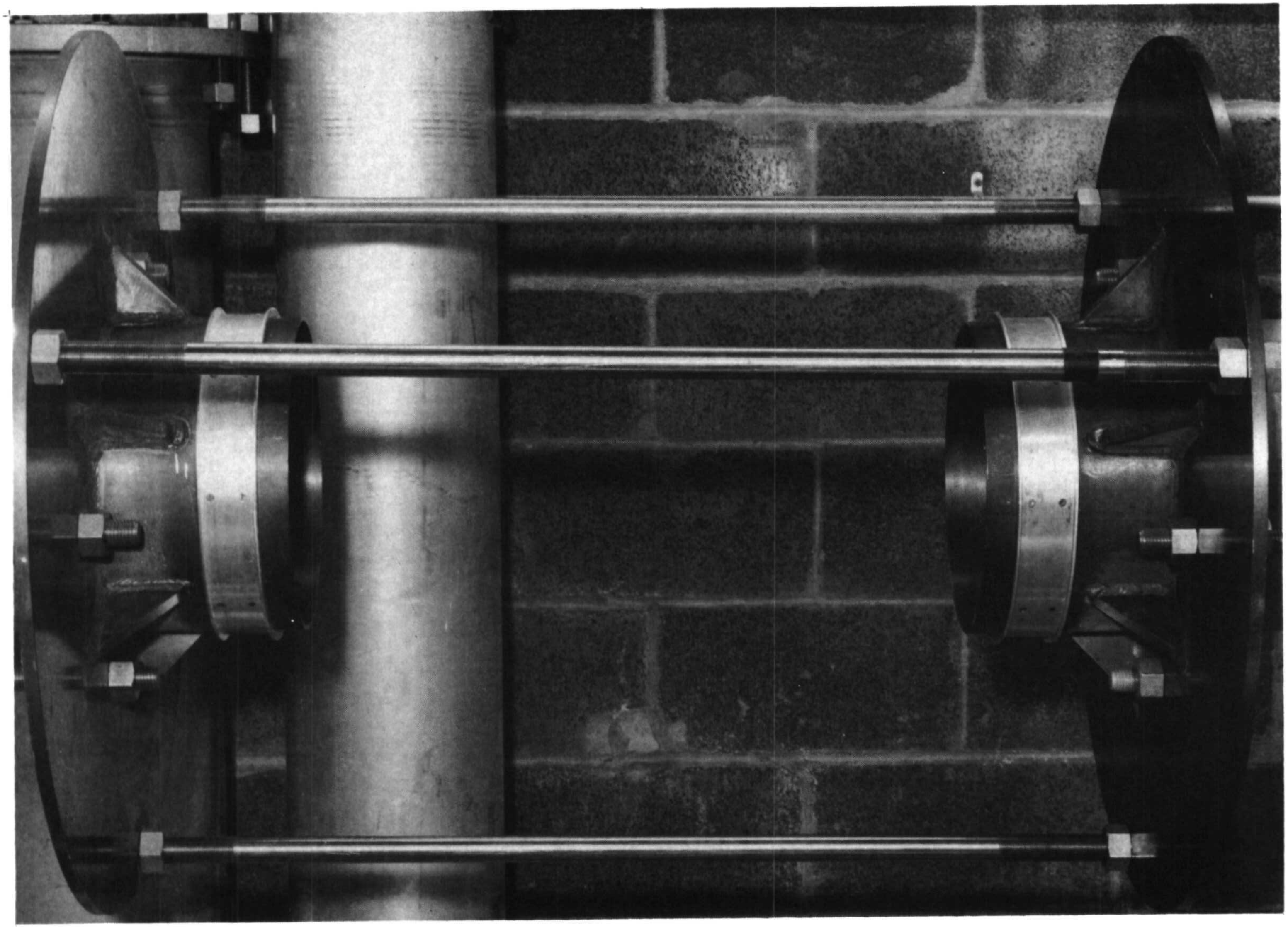

FIG. 5. BRACKET FOR CYLINDRICAL SPECIMENS

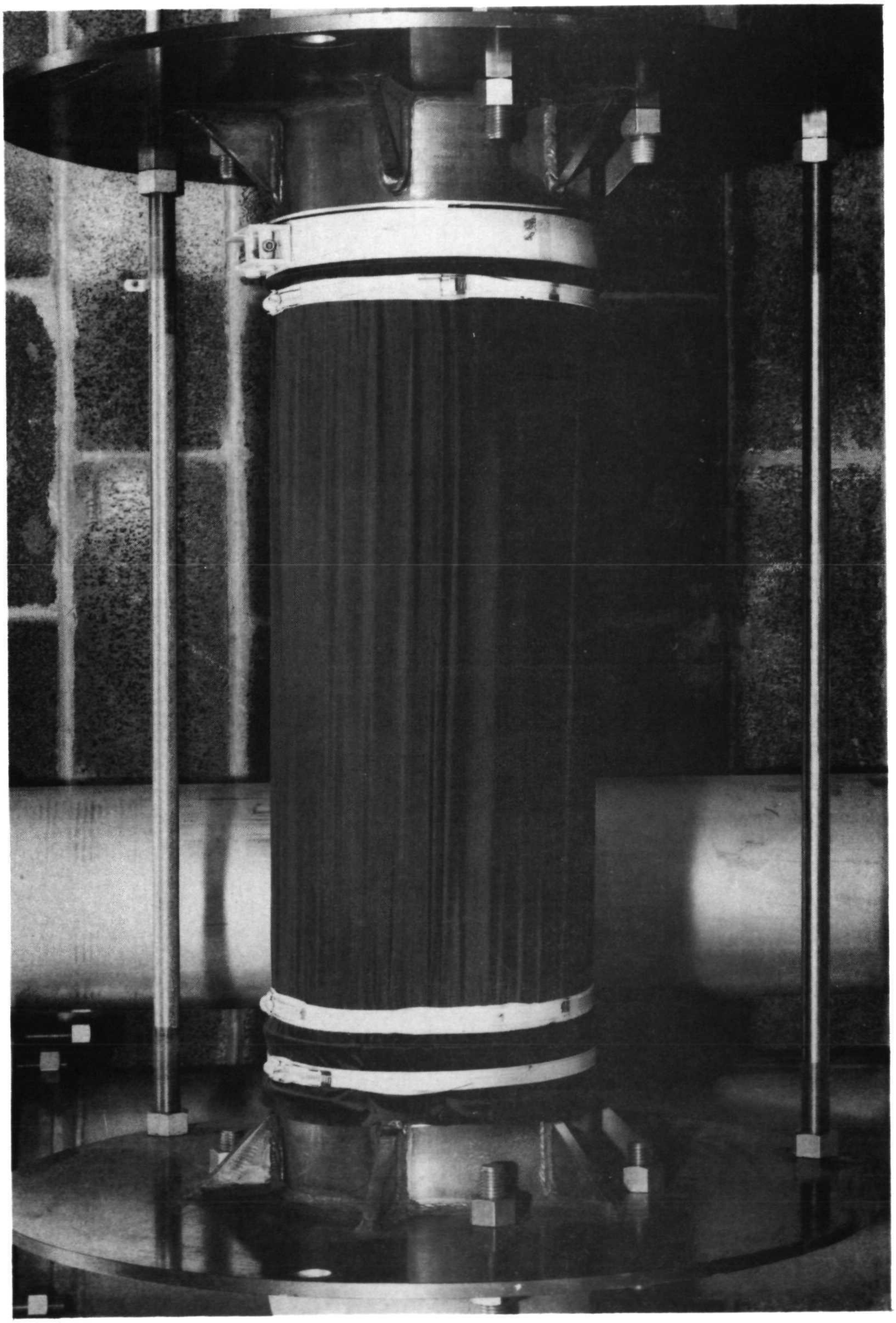

FIG. 6. BRACKET FOR CYLINDRICAL SPECIMENS (WITH FABRIC INSTALLED)

variability in this time turns out to be greater than the time window available for camera operation. To control the firing more closely, we taped a thin wire to a single diaphragm. The wire was heated at run initiation time. Firing then occurred between 0.1 and 0.15 sec following initiation. Standard high-speed movie lights were expected to be unsuitable for this application, since the heat generated might adversely affect the material properties. In their place we used three Sylvania FF33 flashbulbs. These bulbs reach half power in approximately 0.25 sec and remain above half power for a period of approximately 1.35 sec.

Figure 7 shows the operation of the photographic system, including the appropriate delays for insuring that all portions of the system operate during the event.

Fabric Specimens

The flat circular specimens were made of 1.8 oz per sq yd coated dacron; 0.001, 0.002, 0.003 and 0.005-in.-thick mylar; 0.0095-in.-thick surgical rubber; and 1.1 oz per sq yd ripstop nylon parachute cloth. Specimens of 1.8 oz per sq yd coated dacron constructed in the form of a sock and a cylinder were also tested. The cylindrical specimens varied in length from 18 to 36 in. and were fabricated by sewing a seam along the length of the specimen. To reduce any leakage through the seam, each of these specimens was lined with 0.0095-in.-thick surgical rubber. The sock specimens were formed from 36-in.-long cylindrical specimens by sewing closed one end. These specimens were also lined with the 0.0095-in.-thick surgical rubber. The four types of specimens are illustrated in Fig. 8.

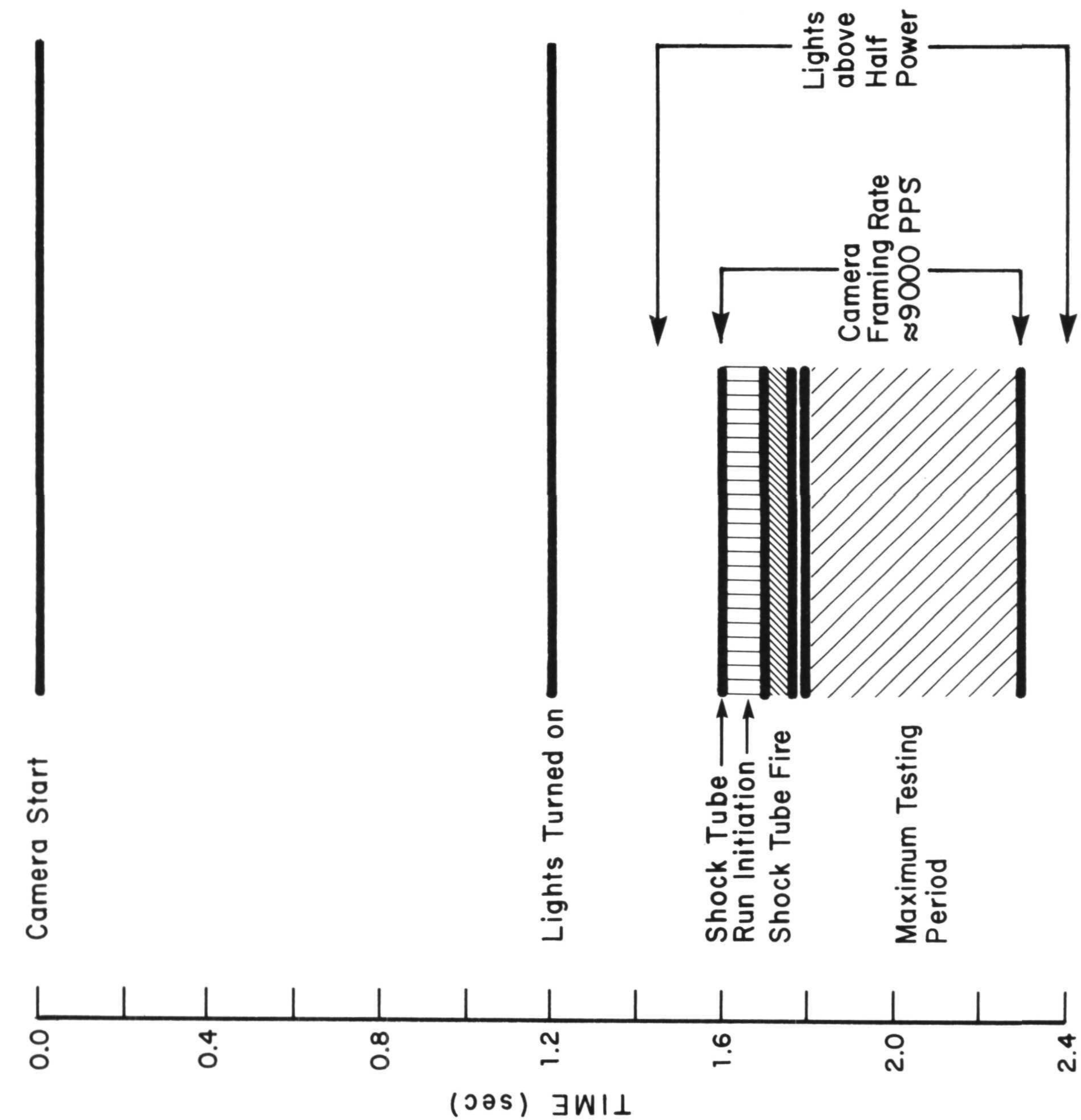

FIG. 7. SEQUENCING FOR CAMERA OPERATION

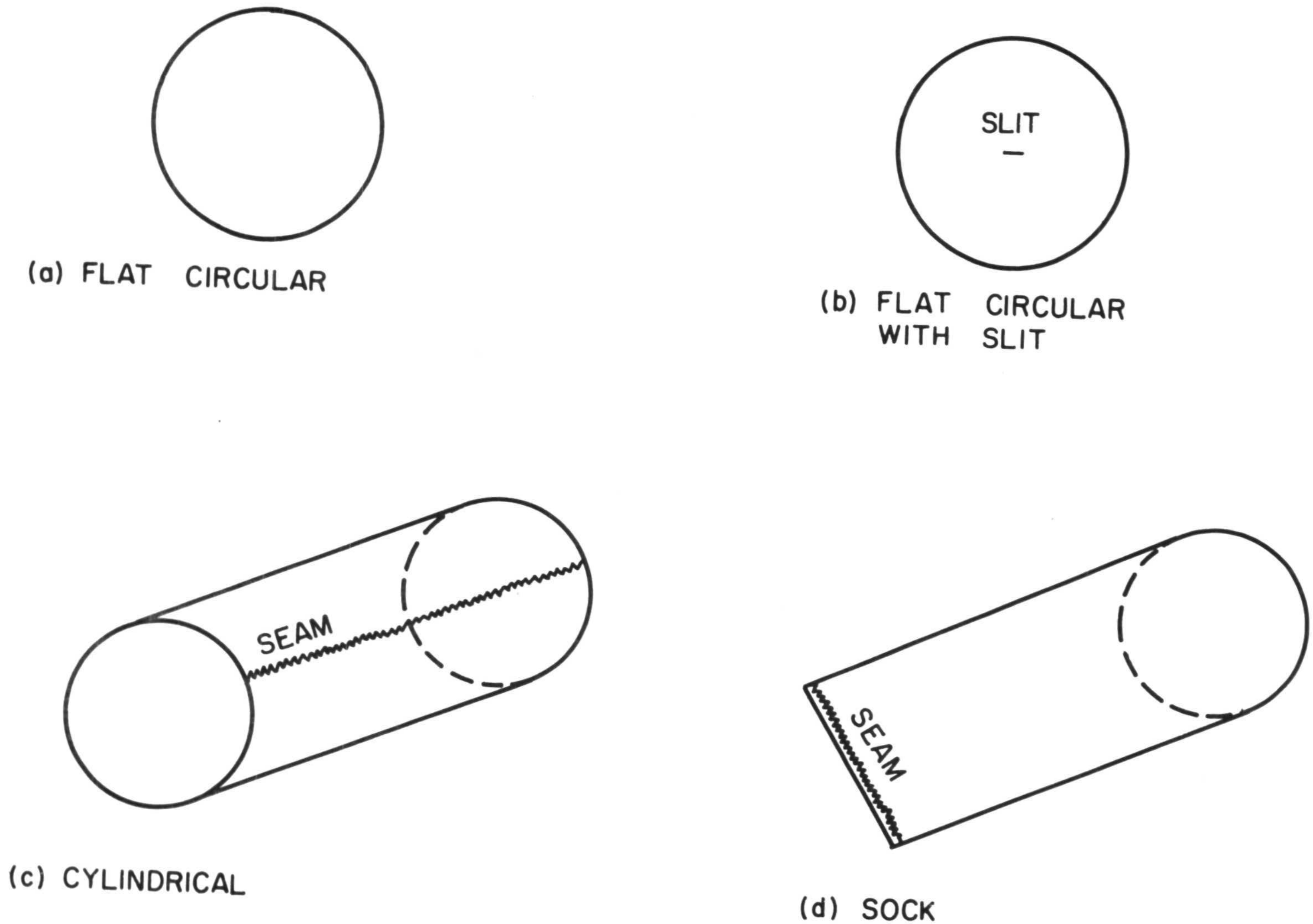

FIG. 8. SPECIMEN TYPES

TEST PROCEDURE

During the static tests the specimens were loaded in 1-psi increments until failure. In the dynamic tests the driver section was loaded to an initial trial pressure and the shock tube was fired. If the specimen failed at this pressure, then the specimen was replaced and the driver pressure was lowered until no failure occurred. If the specimen did not fail, driver pressure was increased for the next run.

The test program was composed of approximately 120 runs, summarized in Table I.

Tests not included in the matrix were used to determine the timing sequence for photography.

TABLE I. TEST MATRIX

Specimen		Number of Tests	
Type	Material	Static	Dynamic
Flat circular	1.8 oz/yd^2 coated dacron	3	12
Flat circular with seam across diameter	1.8 oz/yd^2 coated dacron	16	0
Flat circular with 1-in. slit at center	1.8 oz/yd^2 coated dacron	5	7
Cylinder	1.8 oz/yd^{2}coated dacron	2	8
Sock initially loose	1.8 oz/yd^{2}coated dacron	2	5
Sock initially tight	1.8 oz/yd^2 coated dacron	0	8
Flat circular	Type A Mylar	21	3
Flat circular	0.0095-in.-thick surgical rubber	4	0
Flat circular	1.1 oz/yd^2 ripstop nylon	2	6
Flat circular with 1-in. slit at center	1.1 oz/yd^2 ripstop nylon	3	3
TOTALS		58	52

SUMMARY OF TEST RESULTS

Results are presented in Figs. 9 through 13 of static and dynamic breaking pressures for the specimens given in Table I. These results have been grouped to illustrate diaphragm selection, static seam efficiencies, static breaking pressures, dynamic breaking pressures, and the ratio of dynamic to static breaking pressures. Raw data points are shown on the figures to illustrate the spread in the data. High-speed movies of a typical failure of each type of specimen were taken but are not included with the report.

Diaphragm Selection

In selecting diaphragm materials, we performed static tests on 0.001, 0.002, 0.003 and 0.005-in.-thick type A mylar specimens. In addition, we performed a number of tests on double thickness 0.005-in-thick diaphragms. Data for these tests are shown on Fig. 9, where each dot represents a separate test. The static breaking stress is relatively linear with thickness throughout the range tested. However, thicker diaphragms probably will exhibit nonlinear effects that will reduce the slope of this curve. It is important to observe that the static breaking stress of a particular thickness mylar diaphragm may vary from 20 to 40% depending on such factors as material nonuniformity and installation procedure. This variance is particularly important for a single diaphragm shock tube, since run pressure can vary by 20 to 40%, but not particularly important for double diaphragm shock tubes where diaphragms are loaded only to approximately 50% of their breaking pressure prior to run. (See Ref. 6 for full discussion of double diaphragm operation.) Note that the breaking stress of a double thickness of 0.005-in.-thick mylar is approximately 55 psi, which indicates that if diaphragms are stacked then some reduction must be applied to the sum of their breaking strengths to get the breaking strength of the stack (i.e., 0.9 in this case). When only a limited selection of diaphragm materials is available, stacking the diaphragms will greatly expand the usable range of pressures.

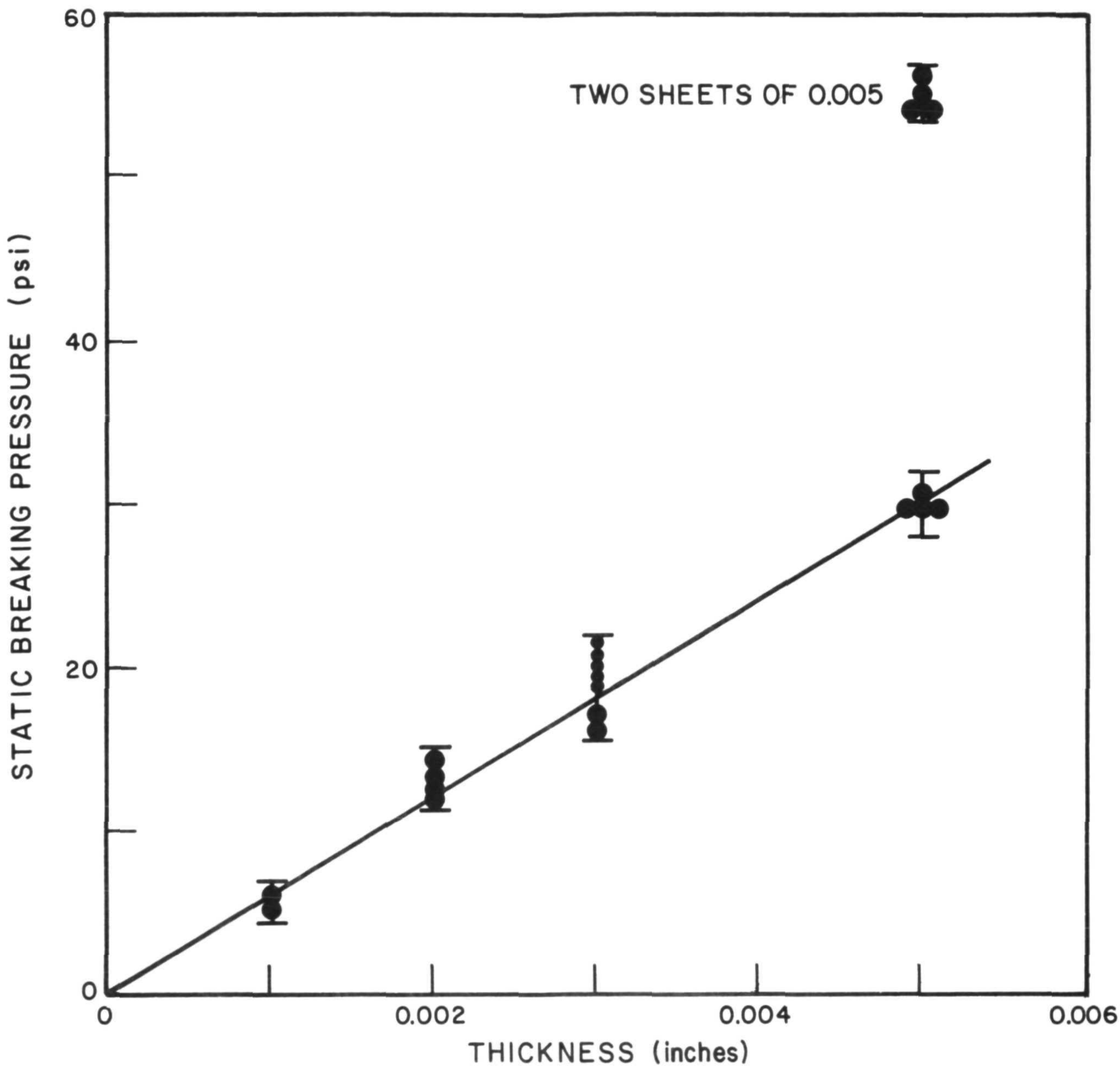

FIG. 9. STATIC BREAKING PRESSURE OF 10.5 INCHES DIAMETER FLAT CIRCULAR TYPE A MYLAR SPECIMENS AS A FUNCTION OF THICKNESS

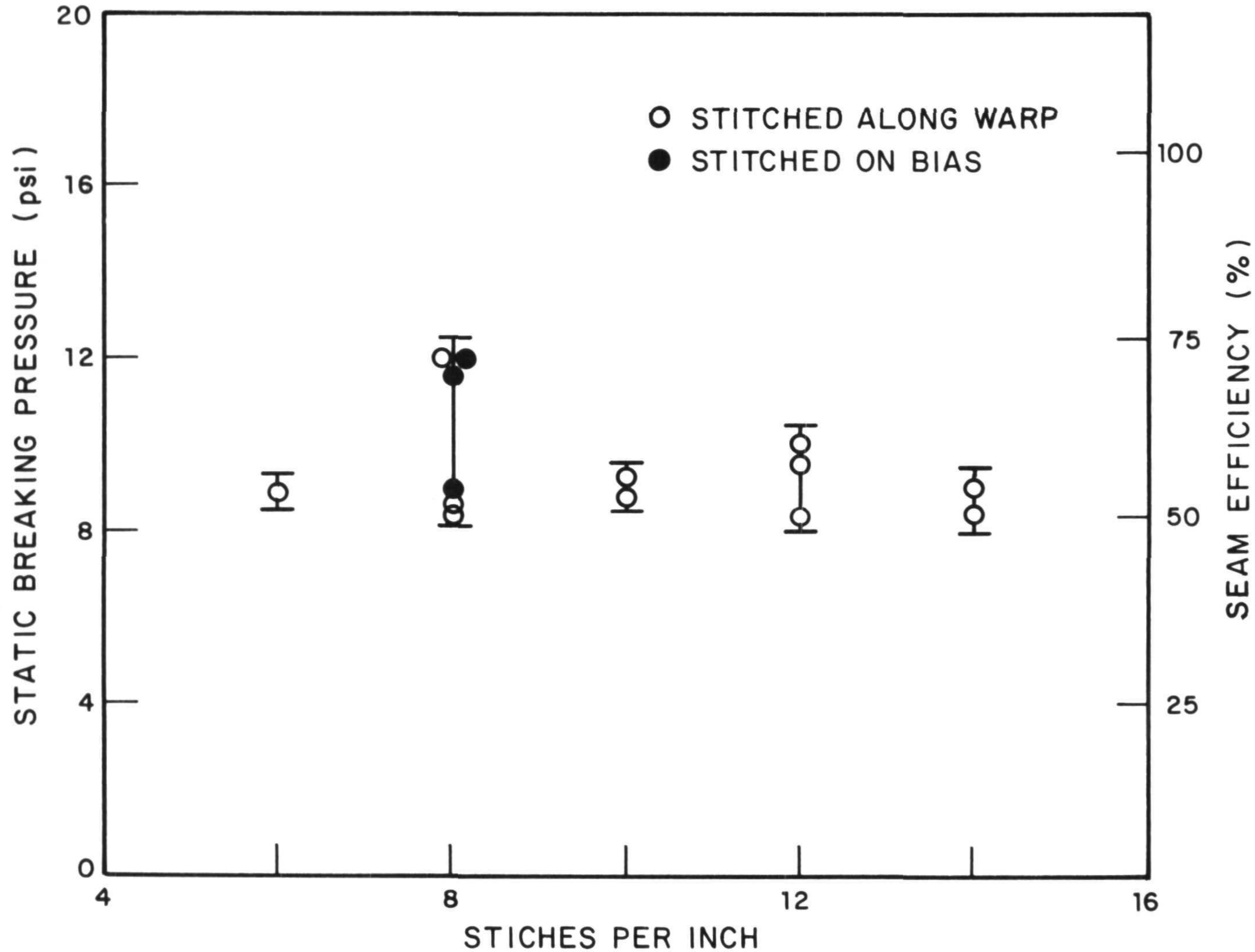

FIG. 10. STATIC BREAKING PRESSURE OF FRENCH FELL SEAMS SEWN DIAGONALLY ACROSS A 10.5 INCH DIAMETER 1.8 OZ/YD^2 COATED DACRON SPECIMEN AS A FUNCTION OF NUMBER OF STITCHES PER INCH

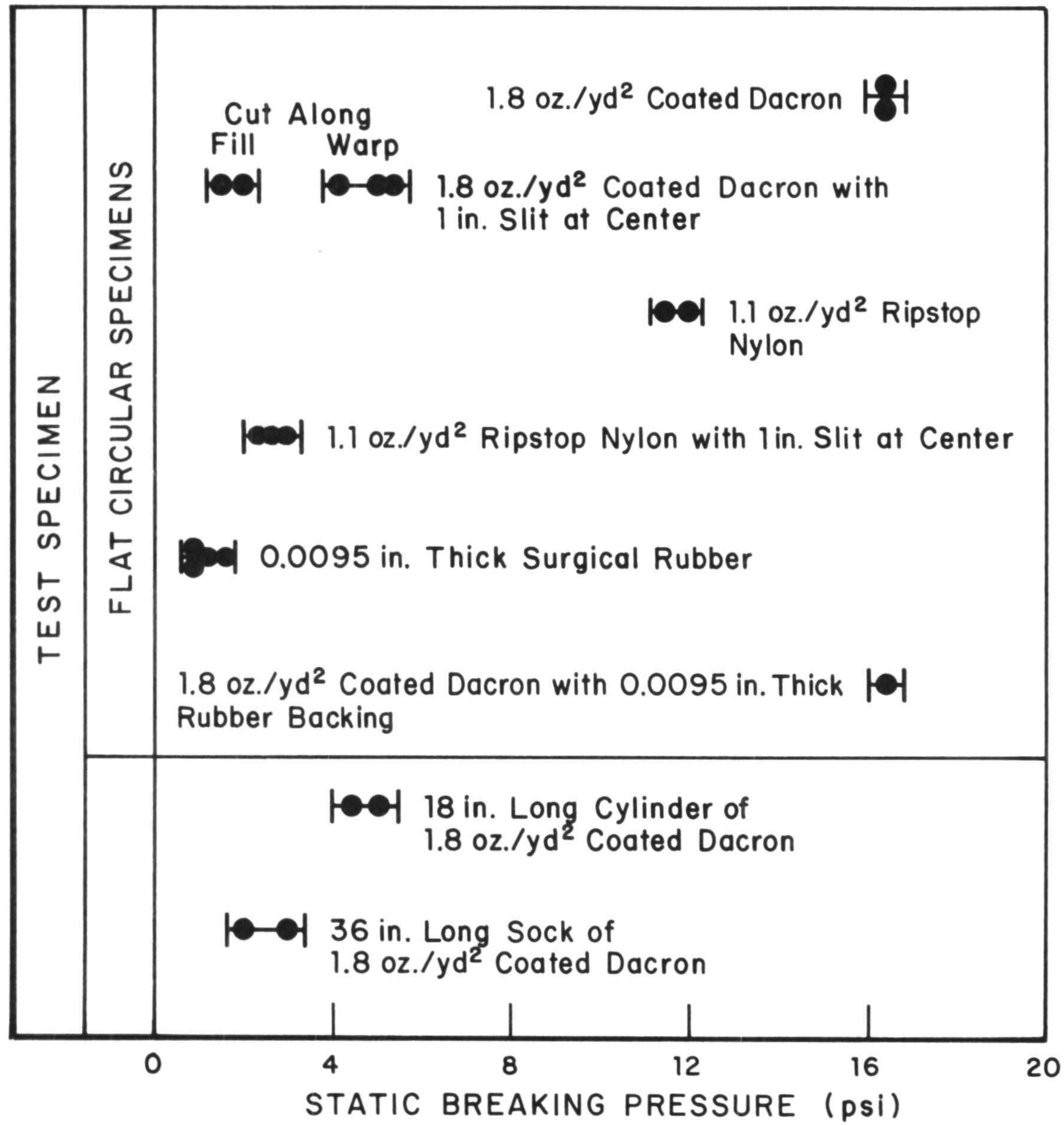

FIG. 11. STATIC BREAKING PRESSURE OF VARIOUS SPECIMENS

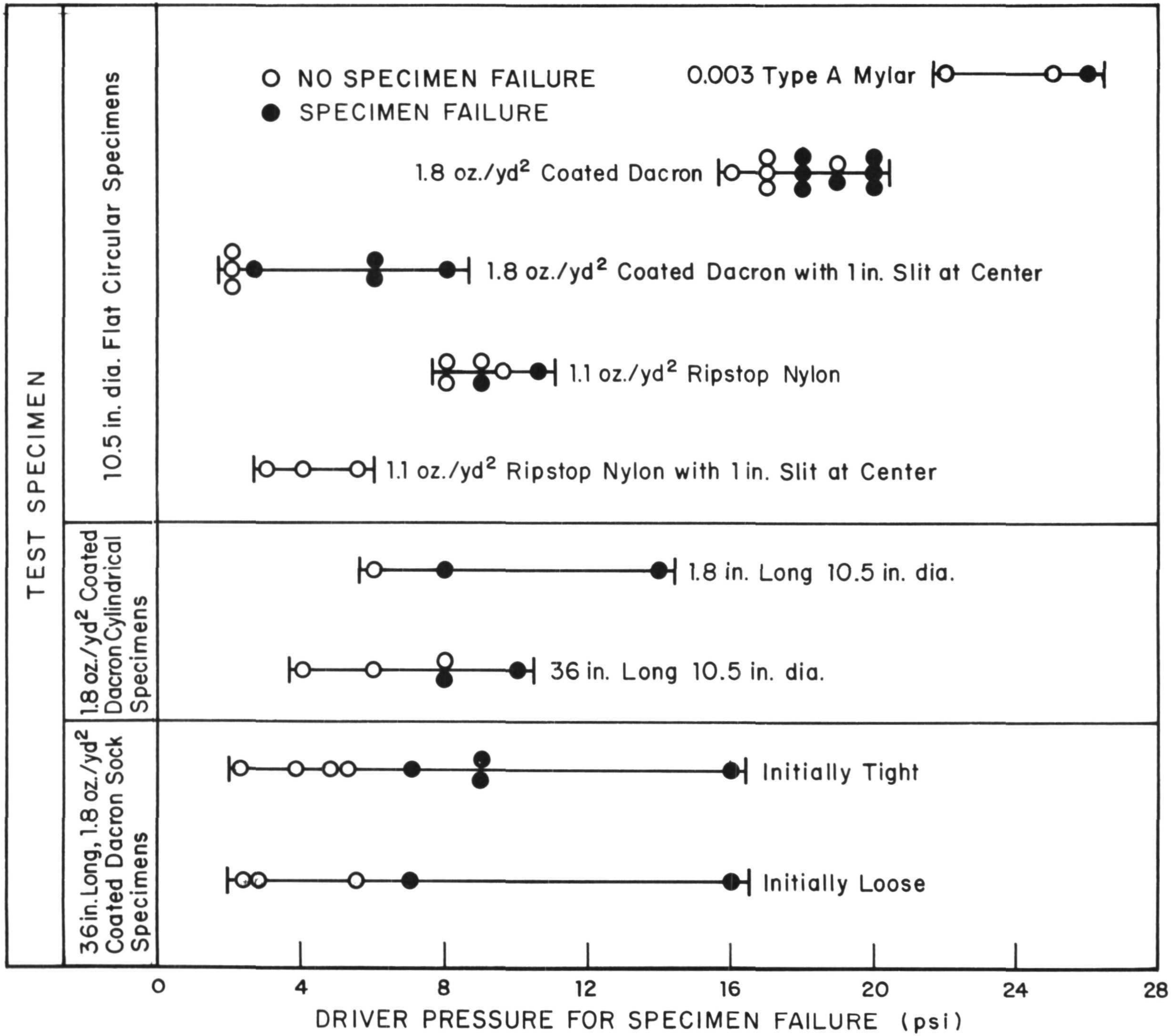

FIG. 12. SHOCK TUBE DRIVER PRESSURE REQUIRED TO BREAK VARIOUS SPECIMENS

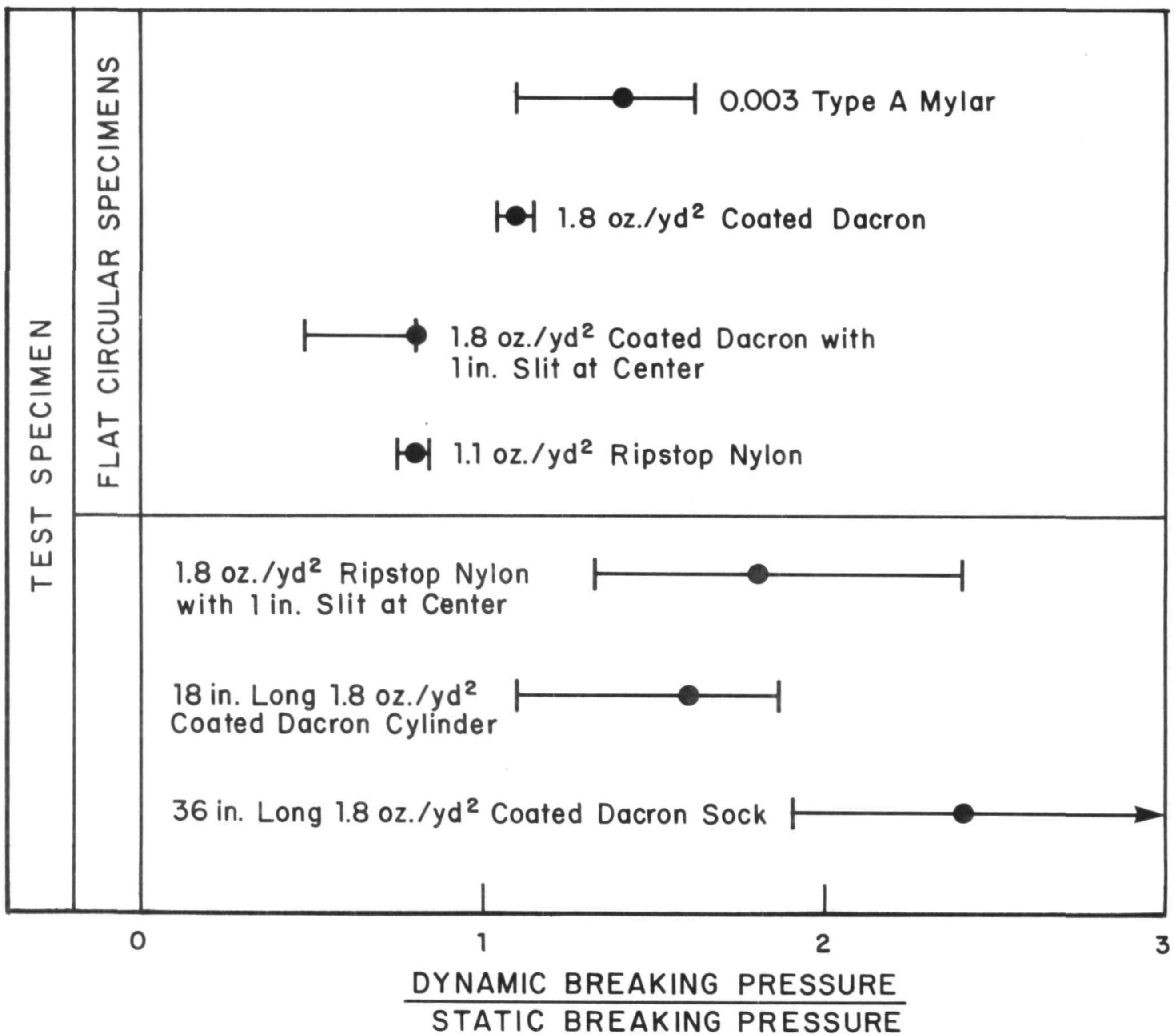

FIG. 13. RATIO OF DYNAMIC TO STATIC BREAKING PRESSURE FOR VARIOUS SPECIMENS

Seam Efficiency

Prior to conducting tests on the cylindrical and sock type specimens, we performed a number of static tests on the seam efficiency of french fell seams with a single row of stitching. The thread used was a type E dacron thread customarily used to sew 1.8-oz coated dacron. Test specimens were flat circles with a seam running across a diameter. Stitching varied from 6 stitches per in. to 14 stitches per in. as shown in Fig. 10. All specimens were stitched along the warp direction with the exception of three specimens that were seamed along the bias. Figure 10 presents static breaking pressure for the 10.5-in.-diameter flat circular seamed specimens as a function of the number of stitches per in. Seam efficiency is also presented as an alternate ordinate. Note that in these tests breaking pressure or seam efficiency is virtually independent of the number of stitches per in. Tests conducted on specimens where the seam was along the bias rather than along the warp direction did not indicate any difference in seam efficiency. It is somewhat curious that the expected trend of increasing seam efficiency with increasing stitches per in. is not present in the data. It is not known whether this result is attributable to sewing technique or is in fact a result of the biaxial stress applied to the specimen.

In an effort to increase the strength of the seams, we also tried cementing the sections together. These specimens all failed at the junction of the cemented area and the virgin fabric at a load which was less than that of the seamed specimens. Presumably this is caused by the local stiffening of the glued area.

In view of the fact that the results of this portion of the investigation were not as expected, we suggest that additional testing be performed to determine the reason for the independence of seam efficiency on stitches per in.

Static Test Results

A summary of the static test results for the flat circular specimens is presented in Fig. 11. In order to obtain a valid comparison between static and dynamic tests, we

backed seamed or porous materials with 0.0095-in.-thick surgical rubber to eliminate porosity. As noted on Fig. 11, the static breaking stress of the rubber is less than 2 psi. This breaking pressure is significantly below the breaking pressure of the materials being evaluated and therefore the rubber backing should not contribute to the test results. To evaluate this hypothesis, we performed static tests of specimens of 1.8-oz coated dacron with and without rubber backing. As can be seen from Fig. 11, there was no change in the breaking pressure.

We also statically tested specimens of 1.8-oz coated dacron with a 1-in.-long slit cut in the center. Porosity was eliminated from these specimens by backing them with the surgical rubber. Static breaking pressure for these specimens was considerably lower than that of the virgin fabric and for some tests was on the order of that for the rubber itself. In addition, the tests indicated that cuts along the fill direction caused the fabric to break at a pressure of approximately 40% of that required to break specimens cut along the warp direction. We noted in these tests that the rubber bulged through the tear, possibly cuasing large stresses at the tip of the tear and therefore causing premature failure. These tests brought up the question of whether or not a ripstop weave would have a pronounced effect on the performance of torn materials. We therefore statically tested 1.1-oz ripstop nylon parachute material backed by surgical rubber both with and without the 1-in. slit in the center. These results are also presented in Fig. 11. As can be noted from the figure, the virgin nylon material has a lower breaking pressure than the dacron; however, the direction of the tear in the nylon did not influence its breaking strength. The nylon with the tear did have a higher breaking stress than the dacron with the slit along the fill direction.

Dynamic Test Results

The dynamic tests consisted of firing the shock tube at a specified driver pressure and then noting whether or not driver pressure was sufficient to fail the specimen under consideration. Specimens were replaced following

each test independently of the occurrence of a failure. The results of the dynamic testing program are presented in Fig. 12. Specimens that did not fail are denoted by dots and specimen failures are denoted by crosses.

The figure illustrates that for both the dacron and nylon specimens, the 1-in. slit at the center very much degraded the dynamic load carrying capabilities. In contrast to the static test results, the direction of the slit in the dacron did not affect the driver pressure required to fail the specimen. As in the static tests, the virgin dacron material required higher pressures to break than did the nylon. However, the nylon with the 1-in. slit at the center required higher driver pressures to obtain failure.

Results of a number of tests run with flat circular specimens, particularly with the virgin dacron and nylon specimens, showed that breaking pressure is not quantified by a single number but rather by a band where failure is undertain. Tests were also run of cylindrical specimens of dacron 18-in. and 36-in. long. Although more tests would have to be run to narrow the band of uncertainty on the breaking pressure, it is clear that the pressure required is virtually independent of specimen length. Inspection of the high-speed photographs of failures of these specimens indicates that failure occurs initially at the seam. This mode of failure is independent of specimen length, hence the above result.

Inspection of the data on the sock-type specimens indicates that failure is independent of whether the sock is stretched tight before the tube is fired or whether the sock is inserted loosely into the shock tube. This result appears to mean that failure is not dependent on mass effects, which is unexpected. High-speed photographs of the sock specimens reveal seam failures, which could account for the independence on mass. The failure on the tight sock, as shown by the photographs, was evident along the seam and in tearing at the shock tube interface. For the loose specimens, circumferential failures away from the shock tube interface were also observed. This fact confirms the theory that if seaming were better, mass effects would become more predominant. Another indication of the inadequacies of the

seams was the fact that both types of cylinders and both types of socks failed at approximately the same pressure. The degradation of seam efficiency with increasing strain rate has also been pointed out in Ref. 7.

Figure 13 shows the ratio of dynamic to static breaking pressure for the specimens tested. An estimated average value for the ratio is shown as a circle and the bars span the maximum and minimum values which could be computed from the data. The figure illustrates that a number of the specimens tested had higher breaking pressures dynamically than statically. However, two specimens, the 1.8-oz dacron with the 1-in. slit and the virgin 1.1-oz nylon specimen, failed at dynamic pressures that were lower than the static breaking pressure. This result illustrates the point in Ref. 5 that quasi-static tests provide no reliable basis for estimating dynamic rupture energy, since no general relationship exists between breaking tenacity and impact energy to rupture or between impact energy and breaking elongation. This result also confirms the idea that a dynamic testing procedure, at the strain rates encountered in application, must be developed before we can predict ultimate fabric performance.

SUMMARY

A testing program was conducted in which specimens of fabric and mylar were loaded to failure both statically and dynamically. Static tests were accomplished by pressurizing the specimens, and dynamic tests were conducted by firing a shock tube. The results of the study indicate that seam efficiency is degraded by dynamic loads and that a need exists to investigate a seaming procedure which gives an optimum dynamic efficiency. The study also illustrates the lack of correspondence between static and dynamic breaking strengths, thereby indicating that fabrics which have dynamic applications should be evaluated using dynamic testing procedures such as the shock tube loading used in the present program.

REFERENCES

1. Lashbrook, R.V. and Mabry, C.M., "An Investigation of Low Permeability Fabrics and of Suspension and Control Lines for the All-Flexible Parawing," AFFTC Technical Report FTC-TR-69-11, April 1969.

2. Alley, V.L. and Faison, R.W., "Experimental Investigation of Strains in Fabric Under Biaxial and Shear Forces," *J. Aircraft* Vol. 9, No. 1, January 1972.

3. Alley, V.L. and Faison, R.W., "Decelerator Fabric Constants Required by the Generalized Form of Hooke's Law," *J. Aircraft* Vol. 9, No. 3, March 1972.

4. Topping, A.D., "An Introduction to Biaxial Stress Problems in Fabric Structures," Aerospace Engineering, Vol. 20, No. 4, April 1961.

5. Lyons, W.J., *Impact Phenomena in Textiles,* The MIT Press, Cambridge, Mass., 1963.

6. Madden, R. and Clemente, A.R., "Operation Manual for Ten Inch Diameter 300 PSIG Shock Tube," BBN Report No. 2321, October 1971.

7. Krizik, J.G., Mellen, D.M., and Backer, S., "Dynamic Testing of Small Textile Structures and Assemblies," Final Report, Contract No. DA-19-129-QM-1308, Quartermaster R and D Center, January 1961.